

MOTOR LEARNING OF CHILDREN IN HAND AND
EYE COORDINATION WITH INTRODUCTION
OF PRISMATIC DEFLECTION

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INTRODUCTION

THE controlled aiming test as herein described offers opportunity for analytical study of factors involved in hand and eye coördination. It presents a method for using angular deflection in experimentation with young children. Such experimentation gives promise of a contribution toward the solution of that group of problems centered in the Stratton experiment and its recent repetition. Obviously the reaction of the child, who lacks knowledge and understanding of the principles involved and the course of the processes of modification, can provide needed additional data. Ewert (1) states that "the dominancy of receptors in a given environmental situation is greatly influenced by the instruction stimulus. The human being is able to develop a consistent response to either a visual, tactile, kinesthetic, or an auditory stimulus (depending in each case upon

the instruction stimulus), inhibiting the sense data from those receptors which may serve as distractors." This observation points to the value of an approach such as is provided in the more nearly naïve reaction of the child.

HISTORICAL DEVELOPMENT

No report of the combination of an aiming or target test with the principle of prismatic deflection is found in the literature. However, localization of objects as viewed through a prism eyepiece is reported. No record of the use of prismatic deflection in experimentation with children has been discovered.

Helmholtz (2) describes the error to right which occurs with prismatic deflection of the field of vision to the right. He calls attention to the process of learning correct localization in successive trials and to the opposite error occurring immediately upon removal of the prism eyepiece. Sanford (4) describes a similar experiment.

Stratton's (5, 6) classical experiment on vision without inversion, though a drastic application on the vertical axis, was worked out on the same learning principles.

¹ This report is part of a dissertation presented in conformity with the requirements for the Degree of Doctor of Philosophy at The Johns Hopkins University. The work was made possible by a National Scholarship in Child Development 1928-30, from the Committee on Child Development of the National Research Council.

Wooster (8), made investigations to study factors involved in the development of a new spatial coördination. A pair of optical prisms was used. Presumably without knowledge of extent or direction of distortion, the subjects decreased the original error 59 per cent.

Conclusions from Wooster's experimentation are in accord with Stratton's results. "No readjustment to the changed visual situation occurred without definite reaching movements of the hand while the eye was fixed on the visual object."

Wooster (8) formulates the hypothesis that "part of the readjustment which occurred was not a reorganization of response with respect to actual position of the object, but represented an adaptation to particular sensory conditions induced by the wearing of prisms." She states that "it is reasonable to suppose that the readjustment in the standard series was due to the tendency of the subject mechanically to react with the hand in response to the old habitual concept of 'front' associated with head position, rather than to the new definition of 'front' involved in the altered position of the eyes in the head. If so, this would indicate that when there is even a slight disturbance of the customary relationship between ocular-motor habits and general bodily habits, the individual mechanically and unconsciously varies his reactions in such a way as to bring the latter into harmony with the established type of reaction."

Loemker (3) attempted to test the Wooster hypothesis as to habitual tendency to react to "front" as determined by head position rather than eye position. No prisms are used; an

eyepiece is made of 2 short tubes, each having a perpendicular slit. Horizontal adjustment of this slit changes the relation of the axis of the head and of the eyes from coincidence to divergence to right or to left. This device presents a head-eye relationship to a visual object just contrary to that imposed by prismatic deflection.

All Loemker's subjects showed a marked constant error. When the head was to the right of the eye axis, the error was to the right and *vice versa*. His results support the hypothesis advanced by Wooster. Loemker makes the statement that size and also direction of localization error are dependent "upon the coördinations of the individual developed upon his ocular peculiarities."

Ewert (1), in a repetition of Stratton's experiment, has secured quantitative evidence as a basis for the following conclusions:

"1. In all forms of activity where overt localizing are present there is rapid adjustment to the distracting visual interference.

"2. In most of the experiments the newly acquired behavior during visual inversion did not persist in measurable form upon removal of the lenses.

"3. Behavior from stimulation of more than one receptor is a resultant response initiated reciprocally by the various receptors involved, vision usually taking precedence.

"4. Constant interference during visual disorientation does not prevent steady growth of a habit.

"5. The eyes are readily educable to new compensatory reflexes."

THE EXPERIMENTAL GROUP

Eight nursery school children, 4 boys and 4 girls, are used as reactors.

All are accustomed to laboratory equipment and to varied types of laboratory tests. The members of this group, who are designated by letters A to H, were all born in 1925. At the time of the beginning of the learning series, the oldest was just five years of age, and the youngest was four years and four months old. All the children except one are of native born parentage. The mother in this

aiming device. The reactor stands facing the wooden screen (*S*) in which there is a small rectangular opening, an eye aperture, admitting a lateral sliding binocular eyepiece. The view of a target seen through the eyepiece may be intercepted by a descending shutter (*I*) operating on the back of the screen (*S*). This rectangular screen is high enough for the forearm to be passed under it easily. The

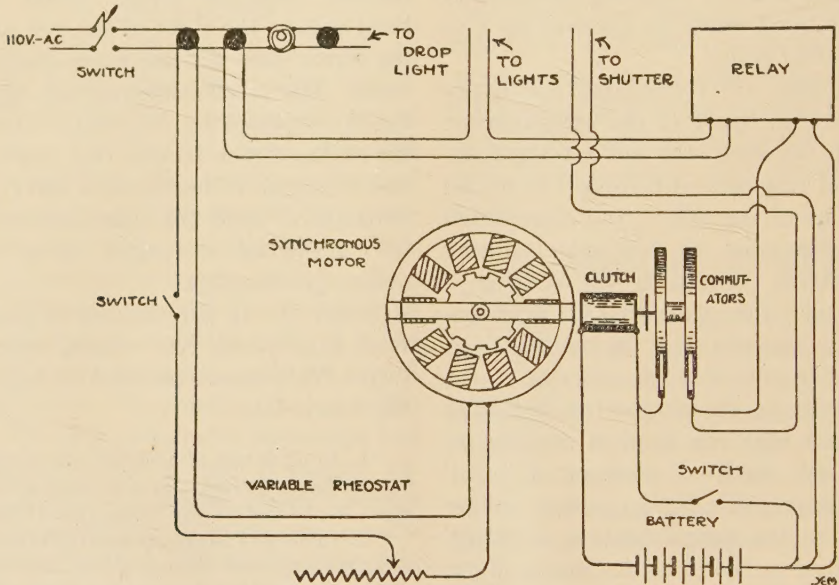


FIG. 1. WIRING DIAGRAM OF APPARATUS FOR HAND AND EYE COÖRDINATION

case is of foreign birth. The group as a whole is of superior intelligence, showing an average intelligence quotient (Stanford-Binet) of 113. All the children are well nourished and reported by medical examination in good health and without defects.

APPARATUS AND METHOD

Apparatus

The apparatus used for testing hand and eye coördination is a controlled

hand is thus entirely free from interference or obstruction of any kind when thrusting at the target.

When the metal shutter (*I*) is raised, four lights flash on in synchronism, bringing into high relief the target, a colored marble, held in the middle of a rectangular field 13 inches from the eyepiece. The marble fits snugly into a hole in the composition board field, and can be punched out by a very light thrust with the brass stylus held by

the child. This sharp stylus is $5\frac{7}{8}$ inches long and weighs $\frac{3}{4}$ of an ounce. Attempts which do not hit the bull's eye (marble) are recorded by the punctures which the pointed stylus makes in a sheet of plain white paper fastened over a thickness of felt across the target board.

The mechanism which controls the shutter is so timed as to allow $\frac{3}{5}$ of a second exposure of the target with intervening non-exposure intervals of 4 seconds. These periods are regulated by two commutators (fig. 1) as described below. In addition to regulating the exposure intervals of the target, the commutators also control the synchronized flashing of the four lights, which accompanies the lifting of the shutter. These lights are mounted on the back of the wooden screen (*S*), thus shielding the child's eyes from glare and facing the target which they periodically illuminate.

Above the shutter is hung a 100 watt incandescent lamp (*R*) in a reflector. This continuous light is used throughout an experimental period to enable the experimenter to see clearly the position of the reactor's hand, and to note the location of the successive stylus punctures.

The aiming device is arranged on an adjustable box-like carriage which slides perpendicularly by weights and pulleys in a wooden framework (*F*) 78 inches high and 50 inches wide. (See diagram, figure 2). On the front of the carriage is the wooden screen (*S*) which contains the eye aperture and which also has, mounted on its back surface, the binocular pieces (*P* and *G*), the interposed shutter (*I*) and the synchronized lights. The rear wall

of the carriage is formed by the target board, which in the diagram, figure 3, has been omitted in order to afford a view of those accessory parts mounted on the back of the front screen (*S*). The vertically sliding carriage thus makes it possible to move the front screen and the target as a unit and to vary their height according to the height of the individual child.

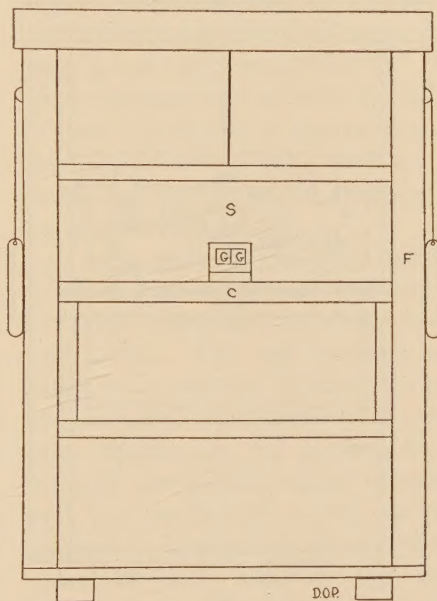


FIG. 2. DIAGRAM OF APPARATUS FOR HAND AND EYE COÖRDINATION. FRONT VIEW

The wooden screen (*S*) which forms the front of the carriage is $39\frac{1}{2}$ inches wide and 14 inches high. The eye aperture in the middle of the lower edge is $3\frac{7}{8}$ inches wide and $3\frac{1}{8}$ inches high. Into position immediately behind this aperture can be slid either of the binocular pieces, which are mounted in a wooden frame easily moved in a horizontal direction.

Two 20° crown glass prisms, each

2 inches square, and having a refracting value of approximately 20 prism diopters, are mounted base left side by side to make the eyepiece (*P*) which displaces the field of vision toward the right. On a horizontal line with the prism eyepiece and in the same horizontally movable wooden frame (*H*) is a plain glass binocular piece (*G*). The plain glass eyepiece

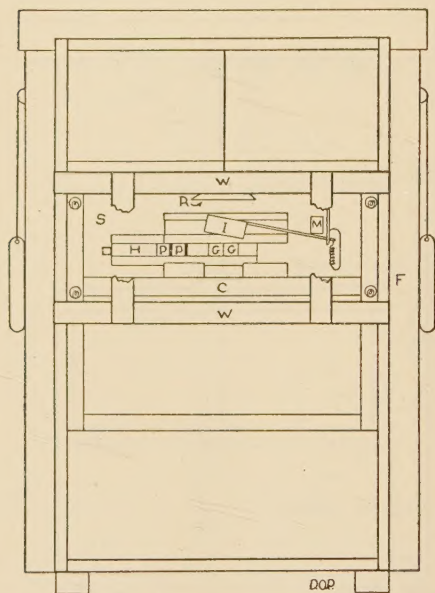


FIG. 3. DIAGRAM OF APPARATUS FOR HAND AND EYE COÖRDINATION. REAR VIEW

is made of two 2-inch squares of plate glass which are mounted, as are the two prisms in the other eyepiece, about $\frac{5}{16}$ of an inch apart. The narrow division space in the eye piece provides for the varying interpupillary distance of the children in the experimental group. A heavy glass is used in order that the child's impression of the thickness of the medium in the two eyepieces may be more nearly equalized. The mounting of the two eye-

pieces (*P* and *G*) in horizontal line on the horizontally sliding frame (*H*) enables rapid change from deflected to normal vision, or *vice versa*, with a minimum distraction of the child. Stops are placed on the back of the wooden screen (*S*) on either side of the eyepiece mounting (*H*). These restrict the excursion of the sliding frame so that the desired eyepiece is quickly placed in correct adjustment with relation to the eye aperture. That part of the wooden framework immediately below the eye aperture is cut away to give room for the nose and to facilitate breathing, thus avoiding the clouding of the eyepieces. A double sateen curtain (*C*) 5 inches long is hung from the lower edge of the screen to discourage any tendency to look below the eyepiece or, previous to the exposure period, to hold the hand at a height approximating the level of the target.

A metal shutter (*I*) 5 inches long and $2\frac{1}{2}$ inches high is mounted $1\frac{1}{2}$ inches behind the eye aperture. This shutter is raised by an electromagnet (*M*) and a coil-spring device. When the magnet releases the shutter at the end of the exposure period, the shutter falls back into its original position behind the eyepiece, thus cutting off the view of the target.

The target is mounted on a composition board field, 48 inches long and 16 inches high, which can be moved laterally to the left or the right in the perpendicularly sliding carriage. The possibility of such lateral movement facilitates adjustment and removal of the target paper. The wooden supports (*W*) of the target board are fastened to the screen by 4 brass rods

which fit into adjustable sleeves fixed to the 4 corners of the screen (S). The use of the adjustable rod and sleeve coupling makes it possible to vary the distance of the target from the eyepiece according to the length of the child's arm. This adjustment is not used in the present experiment, since the arm length of this group of children of the same age shows no such variation as to warrant the expenditure of time necessary for adjustment. The distance of 13 inches from the eyepiece to the target is used throughout.

Two 6-inch stationary spring paper clips fixed on the target board hold a removable target sheet of plain white paper, $24\frac{1}{4}$ inches long and 14 inches high. This target sheet is renewed for each practice period consisting of 10 attempts (thrusts).

In the middle of the target field is a round hole $\frac{9}{16}$ of an inch in diameter, just large enough to hold snugly a cheap clay marble, a "commie," used in a variety of colors. A bag catches the marble when punched out.

Two commutators, which are driven by a synchronous motor of the type used in the Dunlap chronoscope, are used to regulate the time interval of the shutter and the four lights. Power for the motor is derived from a 110 volt, alternating current controlled through a variable rheostat. Wiring is in series (see diagram, figure 1), the circuit to the four synchronized lights being passed through a relay. The lights thus are operated from the motor by means of the commutators and the relay. A 6-volt storage battery furnishes power for the clutch, and for the magnets which control the shutter.

The continuous illuminating drop light above the sliding carriage uses the same 110 volt, alternating current that drives the motor.

Theoretical values of the controlled aiming test

The present apparatus for testing hand and eye coördination was designed by Dr. Knight Dunlap to control, partially at least, some of the highly variable factors encountered in the writer's use of the Whipple free-aiming test with young children. The prism eyepiece was added to the set-up in order to provide a further study of learning involving hand and eye coördination in this more complicated perception pattern.

A main point of departure consists in the use of an eye aperture and an eyepiece interposed between reactor and target. The eye aperture provides for a uniform distance between eye and target for children of the same arm length. In an aiming test, a directed foot position alone, or even a foot position behind a stop or with stirrups is insufficient for the young child who in his eagerness may bend far forward. The repeated cautions necessary for preserving even approximately uniform distance and postural relationship to the target tend to be repressive in nature and may become irritating to the reactor. The use of an eye aperture in a screen produces on the part of the child a practically automatic adjustment to a uniform distance and a uniform bodily posture.

The 5-inch curtain of a somewhat heavy material, as attached to the lower edge of the screen, provides a still more extensive shield to prevent

direct vision of the target. Its flexible nature affects little if at all the free movement desirable in thrusting at the target. The lower edge of the curtain gives the height at which the child's hand is to be held between exposure periods. Thus, without curtailment of freedom of arm movement, a definite designation of a resting hand height, uniformly proportionate to the individual height, is provided. Such a uniformly proportionate preparatory hand height as a starting point for the thrusts is obviously highly important if results of aiming are to be comparable. Here the attempt is made to secure uniformity more perhaps by suggestion than by any other means. The curtain, although no real barrier, may reinforce the suggestion. The mechanism of a hand rest, seems to impose too great a likelihood of obstruction to free movement.

A second point of advantage in the use of an eye aperture lies in the fact that it makes possible the employment of a shutter and a brief exposure period accompanying each thrust. In devising any short-arm aiming test, an important source of error lies in the difficulty of obtaining a comparable type of arm movement. Speed of movement in such a test may be highly variable, and when variable must change the type of muscular coördination and markedly affect precision. In the present controlled aiming device, the necessity imposed by the lights and the descending shutter, as reinforced by the timed vocal command "Punch!" again automatically, tends to produce a satisfactory degree of regularity. The brief exposure period forces a rapid whole arm move-

ment, thus greatly increasing the probability of uniformity in type of muscular coördination used by the different reactors.

The value of the prism eyepiece in furnishing a means of more intensive study of the factors involved in learning a skill which requires fine precision in hand and eye coördination is obvious. The use of the plain glass binocular piece instead of a simple aperture, for practice periods employing normal vision, has definite control value.

Punching a colored marble out of a hole before the lights go off and the shutter comes down may have some of the same age-old qualities of allure-ment as a peep show. Children show little real zest for the Whipple aiming test. In the present test there would seem to be presented a more gratifying type of performance possessing a continuing interest. This interest, it is believed functions as an intrinsic motivation, which is highly necessary for a somewhat prolonged learning experiment.

Procedure

A practice period of 10 thrusts, or attempts, is used throughout the series. This, although a quite short period, is not too brief for the observation of practice effects. It also possesses the advantage of practically eliminating effects of fatigue and boredom which, if present in an experiment such as this using displacement of the visual field, may so cloud the results as to prevent any definite conclusions. The puncture marks of this short arm test cluster somewhat closely around the bull's eye, two thrusts occasionally

falling on the same or nearly the same point. A target sheet containing ten closely grouped punctures can be accurately numbered and scored. A larger number than ten, however, on the same target sheet leads to confusion and inaccuracy. The total practice period of ten exposures calls for a minimum of forty-eight seconds from the moment of the first warning signal. When a marble is struck out, the experimenter without change of position or stopping of the mechanism, inserts another.

The child faces the front screen. He sees the marble target through the plain glass eyepiece and is given the pointed metal stylus with the following instructions: "You are going to have a chance to punch that marble out of the hole. Stand here, and look through the peep-hole. Hold your hand just below the curtain. When the lights flash on, punch the marble out of the hole. You will have to be quick to punch it before the lights go off. I shall first say 'Ready.' Then when I say 'Punch!' you hit the marble."

The motor is started, and the switch is thrown, thus starting the flashing of the synchronized lights and the simultaneous lifting of the shutter. The experimenter holds a diagram of the target field divided into four equal sectors or quadrants around a circle representing the bull's eye. Spacing the vocal signals by the exposure periods, a two second warning signal, "Ready" is given. The signal "Punch" comes with the flashing of the lights. The child makes a quick thrust at the target, dropping his hand immediately afterward during the non-

exposure interval to the lower edge of the curtain. During this rest period the arm is usually held quiet in a position forming approximately a ninety degree angle at the elbow.

Immediately following each of the 10 thrusts of a practice period, the experimenter records by sequential number in the appropriate quadrant of the diagram the approximate position of the puncture. Quadrants are used on the diagram only as a device to secure accurate numbering later of each successive puncture on the target sheet, for from this diagram the number of each stylus contact with reference to its place in the sequence of ten attempts is transferred to the actual punctures as appearing on the target sheet. A separate diagram is necessary for each practice period.

The procedure is uniform except for change from one eyepiece to the other as necessitated by the variation in the series. In the plain glass series, obviously the plain glass eyepiece is used, as, in the prism series, the prism eyepiece is necessary. The mixed series requires the quick change of eyepiece after the fifth thrust.

Method of scoring records

A single target sheet shows the record for one practice period consisting of 10 thrusts at the target. The record sheet has in its center a round hole around which are distributed the stylus punctures, each numbered according to its place in the sequence of the 10 successive thrusts. Sequential numbers of the bull's eyes are noted at the top of the record. Millimeter stencils are used to secure three measurements on every punc-

ture. These three measurements show

- (1) Positive (right) or negative (left) distance from the perpendicular axis.
- (2) Positive (above) or negative (below) distance from the horizontal axis.
- (3) Radial distance from the center of the target.

The algebraic sum of positive distances and negative distances from the vertical axis is divided by 10 to find an average figure showing relationship to the vertical axis. This calculation is of particular interest because of the displacement of the field of vision twenty degrees from the vertical axis as produced by the prism eyepiece used in some of the series. Similarly, the algebraic sum of positive distances and negative distances from the horizontal axis is divided by 10 to give an average figure showing a relationship to the horizontal axis. This calculation being uninfluenced by prismatic deflection in any of the series can be used as a control in the prism and the mixed series for comparison with the calculation based upon the influence of deflection. The sum of the radial distances from center is divided by ten to get an average from center.

In the mixed series, which uses prism eyepiece for 5 thrusts and plain glass eyepiece for 5 thrusts, the same measurements, sums and averages are made. However, here they are made on a basis of 5, the 5 prism hits forming one set of calculations and the five plain glass punctures forming a separate set of calculations, thus making two complete sets of calculations for every record sheet in the mixed series. Three distinct relation-

ships based directly upon original measurements are thus calculated and tabulated for every record.

Program of experimental series with theoretical implications

The experimental program used in the test of hand and eye coördination is planned to include four variations: a) An initial practice series using the plain glass eyepiece, 10 practice periods; b) a prism practice series using the prism eyepiece, 10 practice periods; c) a mixed series using prisms for five successive thrusts and plain glass for five successive thrusts, order alternating, 12 practice periods; and d) a final control series coming back to the use of the plain glass eyepiece again, 3 practice periods.

Three weekly practice periods are given, coming on Monday, Wednesday and Friday.

Motivation of performance

The child shows enthusiasm for this test. The "peephole," the flashing lights and the descending shutter add intrigue to the situation, but the activity of "punching the marble" is so planned as to possess high intrinsic motivation. Strong approval is given to all successes. Because of the high intrinsic motivation, only a small extrinsic reward is deemed necessary even for the long experimental program. For three successes in one practice period (ten attempts) the child is allowed to choose a marble to carry to a box in the nursery school.

RESULTS

Data of the prisms experiment are given in tables 1, 2, and 3. Results

TABLE 1

Means and standard deviations of control and deflection series

REAC- TOR	SEX	AGE	TRIALS	INITIAL UNDEFLECTED (GLASS) SERIES						DEFLECTED (PRISMS) SERIES					
				Direction of error											
				Horizontal		Perpen- dicular		Radial		Hori- zontal		Perpen- dicular		Radial	
				M	σ	M	σ	M	σ	M	σ	M	σ	M	σ
H	F	4:5	10	-.1*	4.7	3.6	5.3	17.1	4.0	3.1	5.8	5.1	4.5	13.2	4.5
E	F	4:9	10	-1.8	3.6	4.7	9.6	20.1	4.7	9.6	10.5	-2.4	4.7	20.5	8.0
F	F	4:4	10	3.5	6.2	2.9	12.4	22.4	12.3	13.0	7.9	.2	7.2	19.6	8.1
D	F	4:9	10	-3.6	2.8	-5.6†	11.7	23.7	11.2	4.7	7.0	-2.9	6.9	20.2	5.6
Mean	F	4:7	10	-.5	4.3	1.4	9.8	20.8	8.1	7.6	7.8	0	5.8	18.4	6.5
B	M	4:5	10	5.2	3.8	-.2	6.8	16.2	4.4	13.3	3.7	4.0	5.9	20.2	6.2
G	M	4:5	10	-.6	3.3	-8.1	4.0	17.4	2.8	7.7	9.1	1.0	3.8	20.0	5.8
A	M	5:0	10	5.2	3.5	.6	7.9	19.7	6.9	6.1	4.6	-3.9	5.8	19.3	2.7
C	M	4:10	10	1.7	7.9	6.9	4.8	19.8	8.8	10.9	7.5	-.8	7.7	25.4	6.0
Mean	M	4:8	10	2.9	4.6	-.2	5.9	18.3	5.7	9.5	6.2	.07	5.8	21.2	5.2
Mean	F-M	4:7	10	1.2	4.5	.6	7.8	19.6	6.9	8.5	7.0	.03	5.8	19.8	5.8

* In the horizontal means the minus sign denotes direction left of the center.
† In the perpendicular means the minus sign denotes direction below the center.

TABLE 2

Means and standard deviations of alternate series

REACTOR	SEX	GLASS FIRST						PRISMS FIRST					
		Horizontal		Perpendicular		Radial		Horizontal		Perpendicular		Radial	
		M	σ	M	σ	M	σ	M	σ	M	σ	M	σ
E	F	-26.1	5.8	-30.4	14.0	44.1	9.3	-1.2	6.0	-24.4	16.0	32.0	11.1
F	F	12.3	18.8	-17.4	7.1	33.8	16.1	27.6	3.0	-7.7	7.7	35.5	4.5
D	F	-10.6	6.1	-3.3	2.9	22.0	2.1	10.1	8.0	-5.9	6.6	22.4	4.7
Mean	F	-8.1	10.2	-17.0	8.0	33.3	9.2	12.2	5.7	-12.7	10.1	30.0	6.8
B	M	-7.7	9.4	-3.8	10.0	23.0	20.0	15.7	3.4	-.6	9.1	21.9	5.9
A	M	-10.6	5.3	-12.4	6.8	21.1	5.5	16.2	6.1	-11.9	8.9	25.3	8.4
C	M	-6.3	10.2	-10.7	21.1	34.4	12.5	11.4	9.1	-2.0	5.2	25.1	4.7
Mean	M	-8.2	8.3	-9.0	12.6	26.2	12.7	14.4	6.2	-4.8	7.7	24.1	6.3
Mean	F-M	-8.1	9.2	-13.0	10.3	29.7	11.0	13.3	5.9	-8.7	8.9	27.0	6.5

recorded are presented as tentative but indicative, not as conclusive. It will be recalled that the scores represent millimeters error, the smaller score consequently indicating the better performance.

Analysis of variations in series

Table 1 gives results in the initial control (glass) and the deflection (prisms) series, each based on 10 trials. Means of the initial control series

ject only to the reactor's preference, whereas such adjustment on the perpendicular plane is conditioned also by the degree of perfection in the placement of the apparatus for the individual.

Comparison of the means of the two series shows in the prisms series the expected increase in horizontal error to the right of the center with an accompanying increase also in the standard deviation. On the perpen-

TABLE 3
Means and standard deviations of alternate series

REACTOR	SEX	GLASS SECOND						PRISMS SECOND					
		Horizontal		Perpendicular		Radial		Horizontal		Perpendicular		Radial	
		M	σ	M	σ	M	σ	M	σ	M	σ	M	σ
E	F	-23.9	5.1	-16.0	14.7	34.1	9.0	8.6	8.0	-25.1	2.8	31.9	4.1
F	F	-7.3	7.6	-5.4	8.0	16.9	4.1	21.9	3.7	-5.1	12.2	29.1	9.8
D	F	-23.6	8.9	-8.6	9.3	30.3	9.1	21.2	5.4	-1.4	4.8	25.0	6.4
Mean	F	-18.3	7.2	-10.0	10.7	27.1	7.4	17.2	5.7	-10.2	6.6	28.7	6.8
B	M	-14.8	4.5	6.2	10.5	24.7	7.9	22.9	7.0	-3.7	11.9	28.3	10.1
A	M	-19.4	9.9	-11.9	16.4	28.6	14.7	16.9	3.9	-9.2	4.2	23.1	3.6
C	M	-17.3	11.0	2.5	14.8	24.2	11.9	33.2	27.4	-3.3	10.2	41.9	24.6
Mean	M	-17.2	8.5	-1.1	13.9	25.8	11.5	24.3	12.7	-5.4	8.8	31.1	12.8
Mean	F-M	-17.7	7.8	-5.5	12.3	26.4	9.4	20.7	9.2	-7.8	7.7	29.9	9.8

reveal only negligible differences between errors on the horizontal and the perpendicular axis, though the standard deviation on the perpendicular axis is perhaps significantly greater. More efficient use of visual cues with regard to lateral deviation in hand and eye coördination as evidenced here may perhaps logically be related to the correction of lateral sway by vision. On the other hand, adjustment to center on the horizontal plane is sub-

dicular axis, on the other hand without disturbance by deflection, definite practice effects are seen in the considerable reduction of the mean errors. On the perpendicular axis the relatively small increase in the standard deviation associated with the considerable decrease in the mean appears especially significant of practice effects, since it might be supposed that greater spread on one axis would ordinarily be accompanied by increased variation

on the other. This tendency appears to be evidenced but by practice is here held considerably in check. That the radial errors remain approximately the same with indeed a small decrease in standard deviation in spite of the manifest disturbance on the horizontal axis is another evidence of the progressive practice effects with reference to errors on the perpendicular. Individual differences as to the amount of increase in mean horizontal error caused by deflection are marked.

In the alternate series which followed the straight prisms series 12 trials are included. Tables 2 and 3 are therefore based on 6 trials with glass first and prisms second and 6 trials with prisms first and glass second.

The means for the 6 trials, in which the five attempts without deflection are scheduled first, appear in table 2 under the caption "Glass first." These data appear theoretically to have the following points of difference from the results recorded in table 1 for the initial glass series:

- a. General practice effects in hitting the target should be more noticeable in table 2 since it shows a later segment of the learning program.
- b. The more lasting as opposed to momentary effects of deflection on the horizontal axis may be expected to show here.
- c. "Warming up" effects within any one trial may be reduced since these trials allow only 5 attempts with glass and 5 with prisms as opposed to 10 attempts of the one or the other in table 1.

Means of the horizontal errors in the "Glass first" trials of the alternate

series exhibit markedly the reversal of error noted as an after effect by Helmholtz (2) and by Sanford (4). A large mean left error almost approximating the mean right error in the simple deflection series, and having a larger standard deviation is recorded. Both perpendicular and radial errors show large increase in the means as well as in the standard deviation in line with the previously expressed expectation of association of increased error on one axis with similar increase on the other. Individual differences are again notable. The alternate series shows marked evidence of general disturbance of the mechanism of the eye reflexes. These first 5 attempts without deflection in the trials placing glass first may be supposed to be the nearest approach to normal vision. Yet even here, confusion is apparent and that not confined to the one axis on which distortion occurs. The large perpendicular error below center is probably due to this general disturbance, and occurs below rather than above because a short thrust from a position below the target is necessitated. The adjustment of the height of the target to the individual need was no less careful during this series. From the data of the alternate series in the 5 attempts without deflection which occur first in order, the more lasting effects of distortion appear sufficient to cause general disturbance in accuracy on both axes. Effects of practice as observable in former series are apparently quite inadequate against the frequent change, at least as shown by mean averages.

Data of the 5 attempts using glass

immediately following deflection are presented under the caption "Glass second" in table 3. These results may perhaps be expected to magnify the effects already summarized for the "Glass first" data. Comparison of the means shows a horizontal error to the left more than twice as large as in the "glass first" data, a striking evidence of the reinforcement of the more lasting by the immediate opposite after effects of muscular compensation. The mean of perpendicular errors is greatly reduced but with increased deviation, and the mean of radial errors is considerably reduced. Under "Glass first" are given the results of the first 5 attempts of these trials and under "Glass second" are recorded the data of the last 5 attempts of the "Prisms first" trials. It therefore appears probable that the reduction in the means of the perpendicular and the radial errors in the "Glass second" data as compared with the "Glass first" data may be due to "warming up" effect during the 10 attempts.

The "Prisms first" attempts of the alternate series may be expected to bear the same relationships to the preceding simple deflection (prisms) series as those listed above for "Glass first" in comparison with the original undeflected series. The same general disturbance of reaction is shown as previously mentioned in connection with the "Glass first" results though perhaps in not an equally irregular manner. The mean horizontal error is greater than in the simple "Prisms" series but with a slightly smaller standard deviation. This increase is presumably due to the elimination of

the last 5 more nearly accurate thrusts at the target. The mean perpendicular error is greater and thrown below the center; the mean radial error is greater; both standard deviations are increased. Individual differences are marked with some greater tendency to uniformity among the boys. Evidence of general disturbance of response pattern is much similar in both the "Glass first" and the "Prisms first" data. It is interesting to note that with the compensatory error to the left in the "Glass first" results is associated a greater perpendicular and also radial error and a much greater variability throughout than with the parallel distortion error of the "Prisms first" data. Such a difference might be due in part at least to an expected greater inaccuracy of the thrusts of the right hand when thrown into the field to the left of center as compared with its efficiency in the nearer field to the right of center.

Data of the "Prisms second" records may be expected in horizontal errors to superimpose upon the more lasting effects of distortion the exaggerations of immediate effects of the same. On the perpendicular axis however whatever increase of efficiency is referable to last 5 as compared with first 5 thrusts should operate to decrease the error. The mean horizontal error is found, as expected, to be much increased. However, means of perpendicular and of radial errors are also larger, which is contrary to expectation in connection with "warming up" effects but in line with the tendency of increased spread on one axis to be associated with increased spread on the other.

The three control trials at the end

of the learning program use uniform stimulation without deflection. The results are presented in tables 4 and 5. They indicate the amount of progress toward elimination of compensatory modifications built up by deflection. The "Glass first" data of table 2 affords the best means of ascertaining progress. Comparison of the means

TABLE 4

Means of final control series (Glass)

REACTOR	SEX	AGE	TRIALS	HORIZONTAL	PERPENDICULAR	RADIAL
F	F	4:4	3	+5.37	-3.3	13.4
E	F	4:9	3	-13.50	-10.1	15.4
C	M	4:10	3	+9.43	+8.1	21.4
B	M	4:5	3	+1.43	+13.8	25.8
A	M	5:0	3	-4.20	-3.03	31.9
Mean..	F-M	4:8	3	-3.9	+1.1	21.6

TABLE 5

Means of final control series (Glass)

REACTORS	AGE	TRIAL	HORIZONTAL	PERPENDICULAR	RADIAL
5	4:8	1	-4.8	-5.6	20.3
5	4:8	2	-3.1	-3.1	22.5
5	4:8	3	-4.1	+7.0	22.0
5	4:8	3	-4.0	+1.1	21.2

shows about one-half of the horizontal error eliminated in 3 trials. Perpendicular error is reduced to near that of the original undeflected series (table 1, Glass). Radial accuracy is slightly less than in this first series. That the return however under conditions of normal vision is fairly rapid is indicated. The need for a longer control series is obvious particularly for study

of the marked individual differences. The individual hits of the final undeflected trials gives a clear picture of the process of recovery from the effects of angular deflection.

Indications of the modifiability of visual reflexes as evidenced in this experiment are in line with the results of Wooster (8) and of Ewert (1). The mechanical progress of this modification as brought out in the reaction of the young child is particularly striking. That modifiability in either direction on the horizontal axis is about equal is to be expected in symmetrical action of the eye muscles. The return under conditions of normal vision is no doubt facilitated by the many daily reactions which tend to overcome the effects of the exceedingly short experimental practice period. As judged by the means it does not appear that any considerable progress toward accuracy in aiming is possible under the changing conditions of the alternating series. The changing stimulus apparently tends to produce a balanced constant error to either side. The selective method by which this balance is achieved is more clearly brought out in the individual thrusts and in the hits.

Sex differences

Boys show superiority in total accuracy as indicated by the radial errors in all except the straight prisms series (table 1). Their superiority under the confusion of the alternate series is quite marked.

Boys show practically throughout a greater uniformity of performance. This might be due to less variability in skill, to less sensitivity to disturb-

ance of pattern or perhaps simply to chance distortion in the small sampling.

The greater uniformity of the boys brings out nothing particularly notable in individual differences. A and B in the simple deflection series show much less original displacement than any of the girls and also less proficiency in correcting for that small displacement.

From the sex differences and from the variation of individual performance, two general groups of factors operative in this test are indicated. Factors of modifiability of eye muscles constitute one group. While obviously a part of precision in aiming, yet in these data rapid and accurate compensatory adjustment of eye muscle mechanisms does not appear to be necessarily associated with precision in aiming under conditions of normal vision. Other factors also are apparently operative in producing fine precision of hand and eye coördination. Disregarding vision in itself, it is tentatively advanced here that two chief factors may be an eye muscle-brain segment and a hand-arm-brain segment which operate in producing the total reaction. It is also possible that either of these segments may possess a variable efficiency which therefore independently conditions the efficiency of the total hand and eye coördination.

Individual differences

Individual differences as shown in the data are marked in amount and in variety.² These are discussed

² Individual tables and case studies are given in the original of the dissertation filed in the library of The Johns Hopkins University.

throughout the text and summarized at the end. The graphs of figure 4 show individual performance of each child throughout the learning program.

Force of movement in striking is an individual variation not measured by the device used.

Practice effects in the individual thrusts

Perhaps the most illuminating study of the compensatory process operative under visual deflection is afforded by analytical examination of the ten successive attempts of each trial.

In the initial undeflected series, the distribution of horizontal errors to right and to left and their variation as to size within any one trial apparently show a large chance effect. However, the number of hits in the last 5 attempts is seen to be considerably larger than in the first 5. Thrust number 10 totals more hits than any other in the undeflected trials. There appears therefore to be some practice effect within the daily trial. Practice effects from trial to trial are recorded in the average error for each trial.

The deflected series shows rather rapid compensation by the eye muscles within each trial. Three children show all positive (right) errors in the first prisms trial, one being able to proceed no nearer than 11 mm. from the vertical axis. The other 2 approach to within 2 mm. of the axis, thus showing excellent progress from the 48 and 44 mm. errors of the first deflected attempt.

Four children show at least one rather large negative (left) error even during the first deflected trial. These occur on the fourth, fifth, seventh and eighth thrusts. Two make a hit on

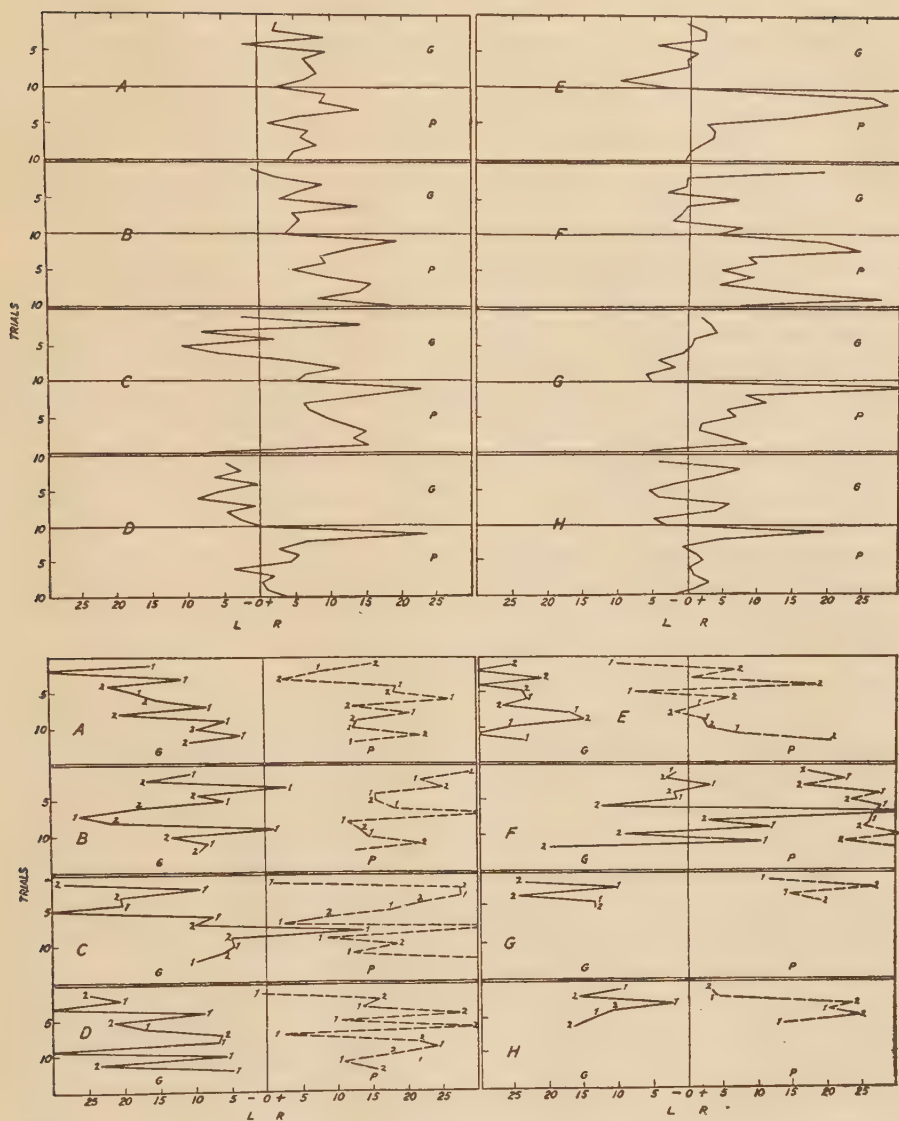


FIG. 4. EYE AND HAND COÖRDINATION

Graphs showing individual performance based on horizontal errors in ten undeflected trials, ten deflected trials, and twelve alternate trials. *G* indicates undeflected (glass) series. *P* indicates deflected (prisms) series. Numerals 1 and 2 in alternate series indicate glass first or glass second and prisms first and prisms second in the trial.

the third and the tenth thrusts of the first prisms trial.

Though there is obviously a certain tendency for the first attempt of a prisms trial to produce the largest error, yet this is not necessarily true. Also in a deflected trial, as mentioned above, the larger number of hits for the last 5 trials indicates general practice effects in the course of the 10 attempts. However, there is operative another more variable influence seemingly inherent in the degree of strain produced in the last preceding response. A considerable over-compensation to the left, or a hit may be countered by a large right error immediately following. A close approximation to equality in successive left and right errors is frequently observed. This influence of strain, fatigue or whatever it may be, probably accounts for some tendency to rhythm which is observed within the 10 attempts of a trial. There is apparently close concentration and progressive improvement through 3 or 4 thrusts followed by relaxation to a wider error to the right and the necessity of again working in to center. The unusual proficiency of Reactor H during the prisms series seems to be accompanied by reduction of the size of the errors and also by a shortening or even an almost entire overcoming of any rhythmic tendency. She shows no tendency toward alternating concentration and relaxation.

Ewert (1) in localization experiments with visual inversion reports a gradual dropping out of errors rather than a reduction in the size of errors. In the present experiment, using angular deflection, there is considerable evi-

dence for reduction of the size of errors during the straight prisms series. However, in the alternate series what gain is made appears to be achieved by increase of hits in later trials rather than by marked decrease in the size of errors. Results for only the alternate series therefore are in accord in this respect with Ewert's observation.

The record of horizontal errors on the first thrust of each prisms trial is quite significant as probably indicating the more lasting effects of compensatory adjustment. Reactor H registers an interesting progress on the first thrusts. The error of the second trial is exceedingly small. After the third trial the error of the first thrust never reaches half of the original error. The two hits and the one over-compensation on the first thrust are particularly notable. Every reactor but C and E shows overcompensation in one or more trials even on the first thrust. Four, including E, show hits on it. C, who holds low score on the prisms series, appears unusually slow to make compensation. His first thrust throughout except on the tenth trial shows large right error. Reactor G, shows a somewhat regular learning process on this first thrust. Beginning with a 50 mm. right error, he proceeds to a 2 mm. right error on the fifth trial. He then proceeds with continued left errors and one hit to the considerable over-compensation of a 36 mm. left error on the tenth trial. Others are more highly variable, some exceedingly so, as to the amount of "hold over" shown by the first thrust.

In the alternating series, the daily averages and the individual means

mask a rather nice selective ability which comes out in the records of some reactors with study of the horizontal errors of the single thrusts. Reactor H, from her excellent scores for the straight prisms series, carries over to the alternating series an excellent compensatory adjustment. Her errors for the first two alternating trials are small in comparison with the errors of the other children on these same trials, and she makes one hit each day. However, with this confusion stimulus pattern, her errors increase markedly; her hits decrease, and she becomes rather indifferent and discouraged by the fifth and sixth trials. It is now believed, particularly from the few hits obtained by any child in the alternating series, that a larger target, perhaps three-fourths of an inch in diameter might be an improvement. By increasing hits and therefore motivation, more clean-cut results might be produced. In an alternating series, the child theoretically proceeds to a balanced adjustment of the deflection error and the after-over-compensation error. This necessitates an increase of deflection errors till the point of balance is reached. Reactor A may be said to reach this point of adjustment in trials 7 and 8 of the alternating series which show a fair approximation of positive (right) and negative (left) errors. With an equilibrium thus established, he proceeds slowly to greater accuracy as shown in the reduction of the error in the first thrusts of trials 10 and 12 in the Prisms first data. The hits in the alternating series illustrate this selective adjustment. Most of the children

score some hits in the first few trials, few if any in the middle period of adjustment but an increase from Trial 9 on, indicating it seems that the child now has some basis of equal compensation from which to work.

Sudden large and unexplainable errors are observable in many of the records. The opinion has been that perhaps these were referable to fatigue or muscle strain, at least to a physiological cause. Ewert (1) also reports these as occurring in touch, sound and visual localization. He is inclined to attribute them to a lapse in the instruction stimulus. If the sudden wide errors in Ewert's results and in the present data are of similar nature, and referable to similar cause, the child's reaction here is perhaps particularly significant, since it cannot be attributed to lapse in instructional stimulus. A different cause is apparently to be sought which may or may not be physiological, as here advanced.

Absence even up to a month as shown in G's record apparently does not effect the course of performance. This evidence of permanence is particularly interesting in view of the rapid adjustment in the very short final series.

SUMMARY

This investigation provides only tentative evidence. Its purpose has been largely exploratory in a field where with young children little or no work has previously been attempted. Though previously emphasized, it is reiterated here that these results from a limited number of reactors are presented as indicative, not as conclusive in any way.

A study has been made of motor learning in hand and eye coördination. For this purpose an apparatus for controlled aiming using prisms deflection has been used. An extended learning program with specific stimulus variations has been carried on using eight children of mean age 4 years 7 months.

Results are as follows:

a. Means of a deflected series as compared with a series using normal vision show increased right horizontal error and simultaneously decreased perpendicular error for the angular deflection series.

b. Progress in a series alternating normal vision and deflection is apparently toward a constant horizontal error approximately equal to right and to left. The increased left error has greater variability and is associated with greater perpendicular and radial error.

c. Final undeflected trials show fairly rapid recovery from effects of deflection.

d. These boys show greater uniformity of reaction throughout and superiority in accuracy except in the straight deflected (prisms) series where the girls lead.

e. Individual differences are marked and highly variable. They are observable under normal vision in amount, variability and direction of horizontal error. With angular deflection to the right the amount of right error, the immediacy, speed, consistency and degree of return all show individual variation. Ability in selective adjustment toward approximation of left and right errors in an alternate series, speed of recovery following deflection

and force exerted in striking show individual variation.

f. Practice effects within a trial are observable by comparison of last five with first five thrusts. Compensation for deflection is rapid within the trial. Decrease in error of the first thrust is observable in successive trials and is apparently indicative of the trend of compensatory modification in any series. Gain proceeds by both reduction of individual errors and increase of hits except in the alternate series. There it is by increase of hits with attainment of right and left approximation.

g. A slight correspondence between efficiency in the different series is seen, though a reactor ranking low in precision under normal vision may make rapid and accurate compensation for deflection.

Suggestions for further experimentation using angular deflection

a. Repetition with adults to secure comparative data between children and adults as to modifiability of compensatory mechanisms. Such data are important as bearing upon the apparently greater emphasis upon visual cues as used by adults for improvement in equilibrium.³

b. Addition of blindfold series to the adult program mentioned above. A blindfold series may bring forth any individual differences in the comparative influence of the hand-arm-brain segment and the eye muscle-brain segment as conditioning the total

³ Data of equilibrium are given in original dissertation, The Johns Hopkins University.

mechanism of hand and eye coördination.

c. Repetition of the same program upon a five-year-old group limited to a two months age range. A target three-fourths of an inch or even an inch in diameter and perhaps a longer alternate series might be tried out. The use of a phorometer for previous

and subsequent test of muscular symmetry constitutes a worthwhile addition to the data.

d. Repetition with a group of left-handed children.

e. Repetition with the target placed a sufficient distance to the left of center to cause it under right deflection to appear at center.

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